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MICRO-EMULSION FUEL ADDITIVE

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20 **Inventors: RICHARD H. HICKS and BEN C. SONG**

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1 BACKGROUND OF THE INVENTION

1. Field of Invention

This invention relates to a micro emulsion fuel additive containing water which improves combustion of hydrocarbon fuels in internal combustion machines.

5 2. Cross References to Related Patents

This application is a continuation-in-part patent application of Serial No. 09/588,029, filed 5 June 2000; which is a continuation-in-part of 09/039,675, filed 16 March 1998, now abandoned; which is a continuation-in-part of 08/629,802, filed 10 April 1996, now abandoned; which is a continuation-in-part of 08/296,457, filed 26 August 1994, now abandoned; which is a
10 continuation-in-part of the parent application 08/153,049, filed 17 November 1993, now abandoned.

3. Relevant Prior Art

It is generally known that water improves combustion of hydrocarbon fuels. There is disagreement as to the mechanism by which the improvement is achieved. Theories include
15 micro-explosions and another theory speaks of an extra hydroxyl radicals. In any event, water in 20,000 parts per million ("ppm") is generally believed necessary to achieve a worthwhile improvement as taught in U.S. Patent 4,315,755. Amounts of water as little 1,000 ppm are taught as achieving some improvement as taught in U.S. Patent 4,396,400.

Water and hydrocarbon fuels do not stay mixed and several strategies have been
20 employed to achieve mixing for combustion purposes. U.S. Patent 1,701,621 teaches significant mechanical agitation of water droplets of greater than 0.4 microns using a small quantity of emulsifying agent. U.S. Patent 3,876,391 teaches water droplets of less than 0.4 microns with more emulsifying agent and little mechanical agitation.

Fuel/water macro-emulsions have been used for many years in boilers where heavy fuel
25 oil is burned to raise steam. U.S. Patent 4,244,702 discloses that these macro-emulsions are very effective in reducing smoke and NO_x emissions while keeping the heat transfer surfaces clean of significant combustion deposits.

1 Grangette et al U.S. Patent 4,396,400 discloses that it is possible to produce a low water
content by adding at least 100 ppm of additional water in forming a micro-emulsion fuel with a
low surfactant content 25 ppm, which gives reasonable emissions reductions when tested in a
vehicle on a chassis dynamometer. However, such a mixture is not stable at a surfactant to water
5 ratio of 0.25:1 and has not been adopted in the real world.

SUMMARY OF THE INVENTION

OBJECTS OF THE INVENTION

It is an object of this invention to provide additional water to hydrocarbon fuels in the
form of a micro-emulsion to enhance fuel efficiency.

10 A further object is to reduce toxic exhaust emissions.

Yet another object is more complete combustion.

DESCRIPTION OF PREFERRED EMBODIMENT

Fuel additive compositions are formulated which can be mixed with commercially
available liquid hydrocarbon fuels (such as gasoline, diesel fuel or jet fuel) to form stable “water-
15 in-oil” type micro-emulsions. Improved combustion and efficiency can be achieved by adding as
little of the composition as needed as to result in 5 to 95 ppm (parts per million) of additional
water in the hydrocarbon fuel. Stability of this low water content micro-emulsion fuel is
achieved with use of high surfactant to water ratios in the additive between 8.0:1 and 0.5:1,
20 preferably between 3.0:1 and 1.0:1 and most preferably 2.5:1. The resulting micro-emulsion fuel
exhibits improved fuel economy and reduced exhaust emissions.

The fuel additive composition should be added to commercially available liquid
hydrocarbon fuels at a dose ratio such that the additional water in such fuel comprises from 5 to
95 ppm by weight of the hydrocarbon fuel. The additive before adding should comprise from
25 10% to 65% by weight of water, preferably 25% to 50% by weight of water; from 0% to 25% by
weight of one or more co-surfactants selected from the group consisting of alcohols, glycols, and
ethers preferably selected from the group consisting of C₁ to C₄ alcohols, ethylene glycol and

1 glycol ethers; and the balance up to 100% by weight of one or more surfactants selected from the
group consisting of amphoteric, anionic, cationic and non-ionic surfactants, preferably selected
from the group consisting of amine alkylbenzene sulphonate, POE (20) sorbitan monooleate, tall
oil fatty acids, oleyl imidazoline hydrochloride and oleamide diethanolamine; and such that the
5 ratio of the surfactant to the water falls within the range from 0.5:1 up to 8.0:1, preferably within
the range 1.0:1 to 3.0:1 and most preferably 2.5:1.

The fuel additive compositions including the preferred ones are prepared by mixing the
above components sufficiently to form a micro emulsion additive.

10 A suitable liquid fuel composition is prepared by mixing a liquid hydrocarbon fuel with
the above described micro-emulsion forming additive so that the composition comprises: from 10
to 400 ppm of one or more surfactants selected from the group consisting of amphoteric, anionic,
cationic and non-ionic types; from 0 to 100 ppm of one or more co-surfactants selected from the
15 group consisting of alcohols, glycols, and ethers; and from 5 to 95 ppm of added water with the
ratio of surfactant to added water being in the range from 0.5:1 to 8.0:1; and the remaining
portion is liquid hydrocarbon fuel. A preferred range for the added water is in the range of 20 to
80 ppm. A preferred ratio of surfactant to added water being in the range of 1.0:1 to 3.0:1. A
20 preference in surfactants is a selection from the group consisting of amine alkylbenzene
sulphonate, POE (20) sorbitan monooleate, tall oil fatty acids, oleyl imidazoline hydrochloride
and oleamide diethanolamines. A preference in the selection of the co-surfactants is selected
from the group consisting of C₁ to C₄ alcohols, ethylene glycol and glycol ethers. A preference
in the liquid hydrocarbon fuel is from the group boiling in the gasoline to diesel fuel range;

25 Internal combustion engines normally show variations in the maximum cylinder pressure
and rate of pressure rise from cycle to cycle which is known as cyclic dispersion. This is due to
variations in turbulence between cycles which vary flame speeds across the combustion chamber.

1 The inventive micro-emulsion when existing within the body of the fuel tends to reduce these
cyclic dispersions. This in turn results in a smoother running engine with lower emissions,
improved fuel economy and reduced engine octane requirements by maintaining cleaner
combustion chambers.

5 The on-set of combustion in both gasoline and diesel engines is governed by chaos
theory. In other words, the way combustion progresses from that point on is extremely sensitive
to the initial conditions. If conditions vary even slightly from cycle to cycle, then the subsequent
growth of the combustion flame will also vary, but to a much greater extent. This extreme
10 sensitivity to initial conditions is the primary cause of cyclic dispersions.

Thus by achieving even an extremely small but beneficial effect at the on-set has a
disproportionally large effect upon the manner in which the combustion subsequently progresses.
This mechanism has not been appreciated and utilized by others in the past.

15 As a gasoline engine accumulates engine hours, its fuel octane requirement increases,
sharply at first, and then more gradually until it stabilizes. This process takes 400 engine hours
on average. This octane requirement increase (ORI) is caused by the gradual build up of carbon
deposits in the engine combustion chambers. Initially, the preferred octane requirement for a
brand new engine might be as low as 78 to 80 octane (R+M/2). After 400 engine hours this
20 preferred requirement has increased to 87 to 89 octane (R+M/2).

The addition of our low water content micro-emulsion to fuels does not significantly
increase the octane rating of the fuel but does significantly reduce the octane requirement of the
engine. Fuel cost traditionally increases with the octane rating of the fuel so that a lower octane
25 requirement translates in to a financial savings.

The lower octane benefit is achieved in two ways. The reduction in cyclic dispersions
reduces the octane requirement. Secondly, a more gradual improvement appears with a dirty

1 engines. Use of the additive results in "micro-explosion" which have a cleaning action which slowly removes the accumulated combustion chamber deposits and in turn slowly reduces the octane requirement.

5 The factors which govern fuel micro-emulsion droplet size and stability at low treat rates are several. Two of the most significant of these factors are the background level of dissolved water already present in the fuel, and the continuous dynamic balance between fuel and water in a typical fuel tank.

10 A typical fuel tanks comprises a vented tank, partially filled with fuel containing some dissolved water, an air space containing some water vapor above the fuel and within the tank, and a small quantity of free water at the bottom of the tank. There exists a continuous interchange of water between these three distinct zones. This interchange is driven in part by ambient temperature fluctuations outside the tank. There are typical day/night temperature cycles, heating caused by fuel re-circulation which occurs in fuel injected vehicles, radiation
15 from hot exhaust pipes and possible exposure of tank surfaces to direct sunlight.

Automotive hydrocarbon fuels typically contain some dissolved water as normal contamination. The maximum quantity of dissolved water varies with the type of fuel and its temperature. Fluids have a solubility constant for water and will vary by class of fuels such as
20 gasoline, diesel, kerosene and not greatly within the class. At normal ambient temperatures (20 deg. C), a typical automotive gasoline (no oxygenates), or diesel fuel, will contain 50 to 100 ppm of dissolved water.

25 The prior art teaches adding 10,000 ppm of emulsified water together with 5,000 ppm of surfactant which renders the background level of 100 ppm of dissolved water of no significant. However, for the present invention, this background level has significance and is not overwhelmed by addition of for example 30 ppm of emulsified water together with 75 ppm of

1 surfactant. Knowledge of the solubility constant for the class of fuel to be treated is an important
essential so that the level of background water is considered and factored into the addition. The
ratio of surfactant to water is increased as necessary so that subsequent to mixing with the fuel,
the ratio of surfactant to water in the additive are of within preferred ratios.

5 It is this background level of water, and the continuing cycle of temperature changes, that
sets the practical lower limit for the concentrated micro-emulsion dose rate. The additive dose
must contain enough water to quickly create an effective initial micro-emulsion, together with
sufficient additional surfactants to accommodate the potential quantities of extra water already
10 dissolved in the fuel, as well as water contamination from the fuel environment.

Unavoidable variations in fuel quality, together with differences in fuel specifications
(reformulated gasoline), means that emulsion droplet sizes can vary considerably, as well as
water volume and hence surface area. For this reason, any kind of laboratory static engine test
15 gives only a general indication of "real world" results. Testing under lab conditions is not a very
reliable indicator of long term micro-emulsion performance.

Survival and consistent performance for a low treat rate fuel emulsion in the "real world"
environment are several orders of magnitude more difficult than in a lab. Also, migration by
some of the oil soluble surfactants away from the emulsion droplets and into the main body of
20 the fuel tends to slowly degrade the fuel emulsion.

Because only a small quantity of about 30 ppm water is being added, a micro-emulsion
forming concentrate can be used as an additive for use in already existing and commercially
available liquid hydrocarbon fuels. This results in the following advantages. Even with a high
25 ratio of surfactant to water is employed, the low water requirement overall results in a low cost
treatment relative to the fuel savings. With less surfactant being used per gallon of fuel relative
to other treatments, there less emissions from incomplete combustion of surfactants. Even if over

1 time the micro-emulsion breaks down, the amount of released water is not large and can be
absorbed by the fuel. The expected improvement may be lost but no damage to the engine will
occur which could lead to possible product liability claims. The smaller volumes involved with
these additives are more readily acceptable to oil refineries and fuel distribution centers because
5 the hardware already exists to incorporate other types of additives on this scale into the base
fuels. If the whole fuel had to be emulsified and mixed after the refining process, the complexity
and effort would dictate against employment.

The additives of the invention are a concentrate that can be conveniently packaged and
10 sold over the counter in retail outlets. Extra surfactants are used to form the additive (increasing
the ratio of surfactant to water) and although this raises the additive treatment cost it also greatly
improves the stability of the final fuel emulsion (grades of gasoline and diesel fuel can vary
considerably from batch to batch). It also allows for the ability to accommodate existing traces
15 of dissolved water, which are usually present as contamination in most commercial fuels. The
water phase of the additive can be used to carry water soluble combustion catalysts well known
to those skilled in the art. These water soluble compounds usually being significantly less
expensive and more readily available than the fuel soluble types currently being employed.

20 Generally liquid fuels do not burn until vaporized. In addition complete combustion
requires intimate mixing of fuel vapor and air in the correct proportions. Micro-explosions help
to vaporize the fuel as well as promote more efficient air/fuel mixing.

Because of the background level of dissolved water already present in the fuel or
expected to be absorbed, it is essential that a sufficiently high surfactant to water ratio be used
25 when producing the concentrated micro-emulsion forming additives of the invention. This ratio
should be in the range from 8:1 to 0.5:1 and preferably 3:1 to 1:1. This is necessary to give the

1 resulting emulsion fuel sufficient extra surfactant(s) to remain stable during the anticipated
emulsion fuel lifetime when extra water will be absorbed from the fuel.

Combustion of liquid hydrocarbon fuels is improved by preparing a concentrated micro-
emulsion forming additive by mixing of a surfactant, a co-surfactant, and water. The following
5 ratios (basis water = 1.0) have been found to be effective:

| <u>Liquid</u> | <u>Preferred Ratio</u> | <u>Ratio Range</u> |
|------------------|------------------------|--------------------|
| Surfactant(s) | 3.0 to 1.0 | 8.0 to 0.5 |
| Co-surfactant(s) | 1.0 to 0.5 | 2.0 to 1.0 |
| 10 Water | 1.0 | 1.0 |

A sufficient amount of the micro-emulsion additive is mixed with the fuel to form a
multitude of dispersed micro-emulsified water droplets, each droplet having an initial diameter
within the range from 0.3 microns to 0.003 microns. These dispersed micro-emulsified water
15 droplets remain in stable suspension within the liquid hydrocarbon fuel until such time as
combustion of the fuel occurs.

Pre-diluting the concentrated additive with kerosene (or some other solvent/distillate) at
the ratio from 50:1 to 1:50 can be used improve mixing. Without adequate mixing, performance
improvements may take as long as 24 hours for the concentrate to properly form into an effective
20 emulsion after simply pouring the additive into the hydrocarbon fuel.

The ratio of liquid hydrocarbon fuel to concentrated micro-emulsion forming additive
should fall within the range from 240:1 to 12,000:1. The treat rates are chosen so as to result in a
micro-emulsified water content added to the hydrocarbon fuel in the range from 5-95 ppm, and
25 typically 20-80 ppm.

1 The following ppms added to the hydrocarbon fuel have been found to be effective:

| | <u>Liquid</u> | <u>Typical ppm</u> | <u>ppm Range</u> |
|---|------------------|--------------------|------------------|
| | Surfactant(s) | 50 to 150 | 10 to 400 |
| | Co-surfactant(s) | 20 to 40 | 0 to 100 |
| 5 | Water | 20 to 80 | 5 to 95 |

Since most hydrocarbon fuels already contain some trace quantities of dissolved water as contamination (typically up to 100 ppm, considerably more for some oxygenated gasolines), it is quite possible to prepare a concentrated additive without using any water at all (although this
10 type of additive would need extra time to become fully active in a typical fuel tank environment).

Although this invention has been illustrated by reference to specific embodiments, it will be apparent to those skilled in the art that various changes and modifications may be made which clearly fall within the scope of this invention.

15 Unless otherwise stated, all ratios, percentages and parts used herein are by weight.

EXAMPLES

Please note that in all of the following examples we have deliberately used various combinations of already existing and commercially available surfactants and co-surfactants to
20 produce our micro-emulsion forming concentrates for use as low treat rate fuel additives. This has been done to show that the additives of the present invention are not limited to any specific combination of particular surfactant(s) or co-surfactant(s). Each additive example has the high surfactant to water ratio (up to 8:1) necessary for long term fuel emulsion stability.

25 There must be many other such additives possible (using different combinations of other surfactants and co-surfactants) that could also be used to produce micro-emulsion forming fuel additives. We refer specifically to Hazbun et al (U.S.#4,744,796) which clearly demonstrates

1 that many different micro-emulsion fuels can be produced using diversely different types of
surfactant and co-surfactant combinations.

These other combinations might be better (or worse) than the specific examples which
follow. Some may have better high (or low) temperature stability, or have improved pour point,
5 flash point, cost, viscosity, corrosiveness, commercial availability, toxicity, freezing point, color,
smell, legislative acceptability, or any number of other particular benefits depending on the
balance of importance prevailing at the time.

The heart of our technique is to produce a low water content liquid hydrocarbon micro-
10 emulsion fuel by using a concentrated micro-emulsion forming additive having a sufficiently
high (up to 8:1) surfactant to water ratio sufficient to give long term fuel emulsion stability.

Similar additives might also be produced by using some other combination of surfactants
and co-surfactants. In other words, it does not really matter which surfactant and co-surfactant
15 combinations are used, provided that they are adequate. Some combinations will probably be
better than others in some way or other, but it is the use of a low treat rate micro-emulsion
forming additive (having a high surfactant to water ratio) which is crucial to the practical
application of our technique.

20 To confirm the validity of our claim to be unique by using a low treat rate micro-emulsion
forming fuel additive (having a high surfactant to water ratio), each of the following examples
(#1 through #12) illustrating our technique uses a different surfactant and co-surfactant
combination to produce a concentrated micro-emulsion forming additive. These additives were
then used to produce low (less than 100 ppm) water content micro-emulsion fuels.

25 These micro-emulsion fuels were then tested to look for benefits similar to those claimed
in the "high water content" emulsion fuel Prior Art (typically, reduced emissions and improved
octane etc.).

1 Co-Surfactants Used for Various Examples:

Although certain chemicals have been mentioned specifically by name as suitable co-surfactants, various other alcohols, glycols, ethers and amines might also be suitable, even some of the amides, diols and aldehydes might prove effective.

5 TABLE 1 (Surfactants Used for Examples #1 Through #12):

| | <u>Trade Name</u> | <u>Chemical Name</u> | <u>Type</u> | <u>Supplier</u> |
|----|-------------------|---------------------------------|-------------|-----------------|
| | Arquad T-50 | Trimethyl Tallow Alkyl Quat | Cationic | Akzo Nobel |
| | Aristonate "M" | Sodium Alkyl Aryl Sulfonate | Anionic | Pilot |
| 10 | Aristonate "L" | Sodium Alkyl Aryl Sulfonate | Anionic | Pilot |
| | Cembetaine CAS | Cocoamidopropyl Hydroxysultaine | Amphoteric | Chemron |
| | Hamosyl C-30 | Sodium Cocyl Sarcosinate | Anionic | Hampshire |
| | Makon 4 | Ethoxylated Alkylphenol | Non-ionic | Stepan |
| 15 | Makon 8 | Ethoxylated Alkylphenol | Non-ionic | Stepan |
| | Norfox TLS | Triethanolamine Lauryl Sulfate | Anionic | Norman Fox |
| | Ninate 411 | Amine Alkylbenzene Sulfonate | Anionic | Stepan |
| | Span 80 | Sorbitan Monooleate | Non-ionic | ICI |
| 20 | Surfonic L24-4 | Linear Alcohol Ethoxylate | Non-ionic | Huntsman |
| | Surfonic L24-9 | Linear Alcohol Ethoxylate | Non-ioni | Huntsman |

Examples #1 through # 12 which follow illustrate the present invention in various forms. We employed seven completely different test vehicles. Three were gasoline powered and four were diesel powered. Two were from USA, three from Europe, and two from Japan. Ages and
25 mileages were also widely different.

When mixing the water, surfactant(s) and cosurfactant(s) to produce the additives used in these examples, the following technique was used:

1 For those additives containing kerosene, this was the first ingredient.

For those additives without kerosene, the co-surfactant(s) was the first ingredient.

Next the surfactant(s) were added using gentle stirring.

Finally, the water was added slowly and stirred until the resulting additive was clear

5 and stable. Regular city water was used in all examples.

TABLE 2 (Percentage Composition For Examples #1 through #12):

| | <u>#1</u> | <u>#2</u> | <u>#3</u> | <u>#4</u> | <u>#5</u> | <u>#6</u> | <u>#7</u> | <u>#8</u> | <u>#9</u> | <u>#10</u> | <u>#11</u> | <u>#12</u> |
|-------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|------------|------------|------------|
| Kerosene | - | - | - | - | - | - | 20 | 30 | - | 20 | 20 | - |
| 10 Arquat T-50 | - | - | - | - | - | - | - | - | - | - | - | 20 |
| Aristonate "M" | - | 35 | - | - | - | - | - | - | - | - | - | - |
| Aristonate "L" | - | 25 | - | - | - | - | - | - | - | - | - | - |
| Cembetaine CAS | - | - | - | - | - | - | - | - | - | - | 10 | - |
| Hamposyl C-30 | - | - | - | - | 4 | - | - | - | - | - | - | - |
| 15 Makon 4 | - | - | - | - | - | 20 | - | 20 | - | 30 | - | - |
| Makon 8 | - | - | - | 25 | - | 10 | - | 10 | - | 30 | - | - |
| Norfox TLS | - | - | - | - | - | - | 7 | - | - | - | - | - |
| Ninate 411 | 70 | - | - | - | - | 30 | - | 30 | 30 | - | 60 | - |
| Span 80 | - | - | - | 55 | 66 | - | 53 | - | 50 | - | - | 50 |
| 20 Surfonic L24-4 | - | - | 40 | - | - | - | - | - | - | - | - | - |
| Surfonic L24-9 | - | - | 40 | - | - | - | - | - | - | - | - | - |
| Methanol | - | - | 10 | - | - | - | - | - | 5 | - | - | - |
| Ethanol | - | - | - | 10 | 10 | - | - | - | - | - | - | - |
| Iso Propanol | 20 | - | - | - | - | 20 | 10 | - | - | - | - | 20 |
| 25 2-Butanol | - | 20 | - | - | 10 | - | - | - | - | - | - | - |
| Ethylene Glycol | - | - | - | - | - | - | - | - | - | 10 | - | - |
| Propylene Glycol | - | - | - | - | - | - | - | - | 5 | - | - | - |
| Water | <u>10</u> | <u>20</u> | <u>10</u> | <u>10</u> | <u>10</u> | <u>20</u> | <u>10</u> | <u>10</u> | <u>10</u> | <u>10</u> | <u>10</u> | <u>10</u> |

1 Total(%) 100 100 100 100 100 100 100 100 100 100 100 100

TABLE 3 (Dose Ratio ppm For Various Examples):

| | #1 | #2 | #3 | #4 | #5 | #6 | #7 | #8 | #9 | #10 | #11 | #12 |
|--------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 5 Hydrocarbon fuel | Gas | #2D | Gas | #2D | Gas | Gas | Gas | Gas | #2D | Gas | #2D | Gas |
| Dose Ratio | 2K | 4K | 2K | 2K | 2K | 4K | 2K | 2K | 2K | 2K | 2K | 2K |
| Kerosene | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 150 | 0 | 100 | 100 | 0 |
| Surfactant(s) | 350 | 150 | 400 | 400 | 350 | 150 | 300 | 300 | 400 | 300 | 350 | 350 |
| Co-surfactant(s) | 100 | 50 | 50 | 50 | 100 | 50 | 50 | 0 | 50 | 50 | 0 | 100 |
| 10 Water | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| Total ppm in fuel | 500 | 250 | 500 | 500 | 500 | 250 | 500 | 500 | 500 | 500 | 500 | 500 |
| Treatment cost/gal | 55 | 17 | 51 | 95 | 99 | 25 | 89 | 52 | 88 | 42 | 56 | 100 |

Note:

a. Dose ratio 2K = 2,000:1, and 4K = 4,000:1. Dose ratio used was based on the
 15 relative emulsifying ability of each particular additive surfactant/co-surfactant combination.
 Some additives were much stronger than others, and could be used at a lower dose rate.

b. Treatment costs/gallon are all relative, based on example #12 (the most expensive)
 being given the arbitrary value of 100.

Example #1

20 Additive #1

Concentrated micro-emulsion additive #1 was prepared by mixing the following
 ingredients:

| | Liquid | Proportion | Ratio | PPM at 2,000:1 |
|----|-------------------|--------------|-------|----------------|
| | Ninate 411 | 70.0% | 7.0 | 350 |
| 25 | Isopropyl Alcohol | 20.0% | 2.0 | 100 |
| | Water | <u>10.0%</u> | 1.0 | <u>50</u> |
| | | 100.0% | | 500 |

1 Test #1a

Concentrated micro-emulsion additive #1 was mixed with 92 octane unleaded gasoline using a treat rate of 500 ppm (2,000:1), or about 50 ppm of additional water. This fuel was then used in a 1990 Lexus 400 (odometer reading about 250,000 miles) for 2 weeks using a typical daily commuter driving pattern.

Concentrated micro-emulsion additive #1 was then mixed with 89 octane unleaded gasoline using a treat rate of 500 ppm (2,000:1), or about 50 ppm of additional water.

The same Lexus 400 vehicle (which normally requires the use of untreated 92 octane fuel) could then use this emulsified 89 octane fuel without any noticeable engine power loss, knocking or pinging, or driveability problems. Testing protocol was generally the CRC E-15-92 vehicle octane number requirement rating.

Test #1b

Mileage testing on this same vehicle showed about a 10% improvement using the 89 octane emulsified fuel over the 92 octane untreated fuel (from 19.0 mpg up to 20.9 mpg).

15 Test #1c

Exhaust emissions were also compared for this vehicle using the California Smog Check protocol (average of 6 tests). Comparison was between untreated 92 octane fuel, and emulsified 89 octane fuel (after the 2 week period described above). Average hydrocarbon (HC) emissions reduced from 20 ppm, down to 16 ppm (a 20% reduction). Carbon monoxide (CO) emissions remained unchanged at 0.00% for both fuels (i.e. below the detection level of the test equipment).

Example #2

Additive #2

Concentrated micro-emulsion additive #2 was prepared by mixing the following ingredients:

| | | | | |
|----|----------------|-------------------|--------------|-----------------------|
| 25 | <u>Liquid</u> | <u>Proportion</u> | <u>Ratio</u> | <u>PPM at 4,000:1</u> |
| | Aristonate "M" | 35.0% | 3.0 | 150 |
| | Aristonate "L" | 25.0% | | |
| | 2-butanol | 20.0% | 1.0 | 50 |

| | | | | |
|---|-------|--------------|-----|-----------|
| 1 | Water | <u>20.0%</u> | 1.0 | <u>50</u> |
| | | 100.0% | | 250 |

Test #2a

Concentrated micro-emulsion additive #2 was mixed with California Reformulated #2 automotive diesel fuel using a treat rate of 250 ppm (4,000:1), or about 50 ppm of additional water.

This fuel was used in a 1972 Mercedes Benz 220D/8 automobile fitted with a 4 cylinder diesel engine (2.2 liter, indirect injection, naturally aspirated). Odometer reading was about 207,000 miles

10 The exhaust smoke level was measured by the "snap-idle" test using a N.T.K. model ST-100 diesel emission smoke tester (manufactured by Komyo Rikagku Kogyo K.K. of Japan).

After 2 weeks of typical commuter driving, the exhaust smoke levels were reduced about 15% (average of 6 tests) from using the emulsified fuel over the untreated fuel (opacity from 14.8% down to 12.6%).

15 Test #2b

Mileage testing on this same vehicle showed about a 6% improvement using the emulsified fuel over the untreated fuel (from 34.0 mpg to 36.0 mpg).

Test #2c

20 The exhaust NO_x level was measured at idle using a "Nonoxor" NO_x analyzer (manufactured by Bacharach Inc., their model #19-7036).

NO_x levels reduced about 5% (average of 6 tests) using the emulsified fuel over the untreated fuel (NO_x levels from 75 ppm down to 71 ppm).

Example #3

Additive #3

25 Concentrated micro-emulsion additive #3 was prepared by mixing the following ingredients:

| <u>Liquid</u> | <u>Proportion</u> | <u>Ratio</u> | <u>PPM at 2,000:1</u> |
|----------------|-------------------|--------------|-----------------------|
| Surfonic L24-9 | 40.0% | | |

| | | | | |
|---|----------------|--------------|-----|-----------|
| 1 | Surfonic L24-4 | 40.0% | 8.0 | 400 |
| | Methanol | 10.0% | 1.0 | 50 |
| | Water | <u>10.0%</u> | 1.0 | <u>50</u> |
| | | 100.0% | | 500 |

5 Test #3a

Concentrated micro-emulsion additive #3 was mixed with 92 octane unleaded gasoline using a treat rate of 500 ppm (2,000:1), or about 50 ppm of additional water. This fuel was then used in a 1990 Lexus 400 (odometer reading about 250,000 miles) for 2 weeks using a typical daily commuter driving pattern.

10 Concentrated micro-emulsion additive #3 was then mixed with 87 octane unleaded gasoline using a treat rate of 500 ppm (2,000:1), or about 50 ppm of additional water.

The same Lexus 400 vehicle (which normally requires the use of untreated 92 octane fuel) could then use this emulsified 87 octane fuel without any noticeable engine power loss, knocking or pinging, or driveability problems. Testing protocol was generally the CRC E-15-92 vehicle octane number requirement rating.

15 Test #3b

Mileage testing on this same vehicle showed about a 10% improvement using the 87 octane emulsified fuel over the 92 octane untreated fuel (from 19.0 mpg up to 20.9 mpg).

Test #3c

20 Exhaust emissions were also compared for this vehicle using the California Smog Check protocol (average of 6 tests). Comparison was between untreated 92 octane fuel, and emulsified 87 octane fuel (after the 2 week period described above). Average hydrocarbon (HC) emissions reduced from 20 ppm down to 8 ppm (a 60% reduction). Carbon monoxide (CO) emissions remained unchanged at 0.00% for both fuels (i.e. below the detection level of the test equipment).

25 Example #4

Additive #4

Concentrated micro-emulsion additive #4 was prepared by mixing the following ingredients:

| | <u>Liquid</u> | <u>Proportion</u> | <u>Ratio</u> | <u>PPM at 2,000:1</u> |
|---|---------------|-------------------|--------------|-----------------------|
| 1 | Span 80 | 55.0% | | |
| | Makon 8 | 25.0% | 8.0 | 400 |
| | Ethanol | 10.0% | 1.0 | 50 |
| 5 | Water | <u>10.0%</u> | 1.0 | <u>50</u> |
| | | 100.0% | | 500 |

Test #4a

Concentrated micro-emulsion additive #4 was mixed with California Reformulated #2 automotive diesel fuel using a treat rate of 500 ppm (2,000:1), or about 50 ppm of additional water.

This fuel was then used in a 1979 Peugeot 504 sedan fitted with a 43 cylinder diesel engine (2.3 liter, indirect injection). Odometer reading was about 117,000 miles.

The exhaust smoke level was measured by the "snap-idle" test using a N.T.K. model ST-100 diesel emission smoke tester (manufactured by Komyo Rikagaku Kogyo K.K. of Japan).

Smoke levels reduced about 6% (average of 6 tests) using the emulsified fuel over the untreated fuel (opacity from 35% down to 33%).

Test #4b

Mileage testing on this same vehicle showed a slight improvement using the emulsified fuel over the untreated fuel (from 37.0 mpg to 37.1 mpg).

20 Test #4c

The exhaust NO_x level was measured at idle using a "Nonoxor" NO_x analyzer (manufactured by Bacharach Inc., their model #19-7036).

NO_x levels reduced about 3% (average of 6 tests) using the emulsified fuel over the untreated fuel (NO_x levels from 65 ppm down to 63 ppm).

25 Example #5

Additive #5

Concentrated micro-emulsion additive #5 was prepared by mixing the following ingredients:

| | <u>Liquid</u> | <u>Proportion</u> | <u>Ratio</u> | <u>PPM at 2,000:1</u> |
|---|--------------------------|-------------------|--------------|-----------------------|
| 1 | Sodium Cocyl Sarcosinate | .3% | 7.0 | 350 |
| | Span 80 | 65.7% | | |
| | Ethyl Alcohol | 10.0% | | |
| 5 | 2-butanol | 10.0% | 1.0 | 100 |
| | Water | <u>10.0%</u> | 1.0 | <u>50</u> |
| | | 100.0% | | 500 |

Note: We actually used 14.3% Hamposyl C-30 in our additive #5. Hamposyl C-30 is 30% Sodium Cocyl Sarcosinate and 70% water. So 14.3% C-30 = 4.3% Sodium Cocyl Sarcosinate + 10.0% water. i.e. we did not need to add any extra water.

Test #5a

Concentrated micro-emulsion additive #5 was mixed with 87 octane unleaded gasoline using a treat rate of 500 ppm (2,000:1), or about 50 ppm of additional water.

This fuel was then used in a 1992 Honda Accord 4 door sedan fitted with the 2.1 liter 4 cylinder, 16 valve, fuel injected gasoline engine. The odometer reading was about 93,000 miles.

After two weeks of typical commuter driving, the exhaust emissions were then compared for this vehicle using the California Smog Check protocol (average of 6 tests). Comparison was between untreated 87 octane fuel, and emulsified 87 octane fuel.

Average hydrocarbon (HC) emissions reduced from 16 ppm down to 15 ppm (about a 6% reduction). Carbon monoxide (CO) emissions remained unchanged at 0.00% for both fuels (i.e. below the detection level of the test equipment).

Test #5b

Mileage testing on this same vehicle showed about a 3.6% improvement using the 87 octane emulsified fuel over the 87 octane untreated fuel (from 32.9 mpg up to 34.1 mpg average).

25 Example #6

Additive #6

Concentrated micro-emulsion additive #6 was prepared by mixing the following ingredients:

| | | | | |
|---|-------------------|-------------------|--------------|-----------------------|
| 1 | <u>Liquid</u> | <u>Proportion</u> | <u>Ratio</u> | <u>PPM at 4,000:1</u> |
| | Ninate 411 | 30.0% | | |
| | Makon 4 | 20.0% | 3.0 | 150 |
| | Makon 8 | 10.0% | | |
| 5 | Isopropyl Alcohol | 20.0% | 1.0 | 50 |
| | Water | <u>20.0%</u> | 1.0 | <u>50</u> |
| | | 100.0% | | 250 |

Test #6a

Concentrated micro-emulsion additive #6 was mixed with 92 octane unleaded gasoline using a treat rate of 250 ppm (4,000:1), or about 50 ppm of additional water. This fuel was then used in a 1990 Lexus 400 (odometer reading about 250,000 miles) for 2 weeks using a typical daily commuter driving pattern.

Concentrated micro-emulsion additive #6 was then mixed with 87 octane unleaded gasoline using a treat rate of 250 ppm (4,000:1), or about 50 ppm of additional water.

The same Lexus 400 vehicle (which normally requires the use of untreated 92 octane fuel) could then use this emulsified 87 octane fuel without any noticeable engine power loss, knocking or pinging, or driveability problems. Testing protocol was generally the CRC E-15-92 vehicle octane number requirement rating.

Test #6b

Mileage testing on this same vehicle showed about a 10% improvement using the 87 octane emulsified fuel over the 92 octane untreated fuel (from 19.0 mpg up to 20.9 mpg).

Test #6c

Exhaust emissions were also compared for this vehicle using the California Smog protocol (average of 6 tests). Comparison was between untreated 92 octane fuel, and emulsified 87 octane fuel (after the 2 week period described above). Average hydrocarbon (HC) emissions reduced

20 ppm down to 10 ppm (a 50% reduction). Carbon monoxide (CO) emissions remained unchanged at 0.00% for both fuels (i.e. below the detection level of the test equipment).

1 Example #7

Additive #7

 Concentrated micro-emulsion additive #7 was prepared by mixing the following ingredients:

| | | | | |
|----|--------------------|-------------------|--------------|-----------------------|
| 5 | <u>Liquid</u> | <u>Proportion</u> | <u>Ratio</u> | <u>PPM at 2,000:1</u> |
| | Kerosene | 20.0% | | 100 |
| | TEA Lauryl Sulfate | 6.7% | | |
| | Span 80 | 53.3% | 6.0 | 300 |
| | Isopropyl Alcohol | 10.0% | 1.0 | 50 |
| 10 | Water | <u>10.0%</u> | 1.0 | <u>50</u> |
| | | 100.0% | | 500 |

Note: We actually used 16.6% Norfox TLS in our additive #7. Norfox TLS is 40% TEA Lauryl Sulfate and 60% water. So 16.7% represents 6.67% TEA Lauryl Sulfate and 10.0% water. i.e. we did not need to add any extra water.

15 Test #7a

 Concentrated micro-emulsion additive #7 was mixed with 87 octane unleaded gasoline using a treat rate of 500 ppm (2,000:1), or about 50 ppm of additional water.

 This fuel was then used in a 1996 Dodge RAM 1500 pick-up truck (fitted with the 5.2 liter V8 “magnum” gasoline engine), the odometer reading was about 16,500 miles.

20 The very next day, exhaust emissions were then compared for this vehicle using the California Smog Check protocol (average of 6 tests). Comparison was between untreated 87 octane fuel, and emulsified 87 octane fuel.

 Average hydrocarbon (HC) emissions reduced from 20 ppm down to 2 ppm (a 90% reduction). Carbon monoxide (CO) emissions remained unchanged at 0.00% for both fuels (i.e. below the detection level of the test equipment).

25 Test #7b

 Mileage testing on this same vehicle showed about a 2.2% improvement using the 87 octane emulsified fuel over the 87 octane untreated fuel (from 18.1 mpg up to 18.5 average).

1 Example #8

Additive #8

Concentrated micro-emulsion additive #8 was prepared by mixing the following ingredients:

| | | | | |
|----|---------------|-------------------|--------------|-----------------------|
| 5 | <u>Liquid</u> | <u>Proportion</u> | <u>Ratio</u> | <u>PPM at 2,000:1</u> |
| | Kerosene | 30.0% | | 150 |
| | Ninate 411 | 30.0% | | |
| | Makon 4 | 20.0% | 6.0 | 300 |
| | Makon 8 | 10.0% | | |
| 10 | Water | <u>10.0%</u> | 1.0 | <u>50</u> |
| | | 100.0% | | 500 |

Test #8a

Concentrated micro-emulsion additive #8 was mixed with 92 octane unleaded gasoline using a treat rate of 500 ppm (2,000:1), or about 50 ppm of additional water. This fuel was then
15 used in a 1990 Lexus 400 (odometer reading about 250,000 miles) for 2 weeks using a typical daily commuter driving pattern.

Concentrated micro-emulsion additive #8 was then mixed with 89 octane unleaded gasoline using a treat rate of 500 ppm (2,000:1), or about 50 ppm of additional water.

The same Lexus 400 vehicle (which normally requires the use of untreated 92 octane
20 fuel) could then use this emulsified 89 octane fuel without any noticeable engine power loss, knocking or pinging, or driveability problems. Testing protocol was generally the CRC E-15-92 vehicle octane number requirement rating.

Test #8b

Mileage testing on this same vehicle showed about a 5.0% improvement using the 89
25 octane emulsified fuel over the 92 octane untreated fuel (from 19.0 mpg up to 20.0 mpg).

Test #8c

Exhaust emissions were also compared for this vehicle using the California Smog Check protocol (average of 6 tests). Comparison was between untreated 92 octane fuel, and emulsified

- 1 89 octane fuel (after the 2 week period described above). Average hydrocarbon (HC) emissions reduced from 20 ppm down to 11 ppm (a 45% reduction). Carbon monoxide (CO) emissions remained unchanged at 0.00% for both fuels (i.e. below the detection level of the test equipment).

Example #9

5 Additive #9

Concentrated micro-emulsion additive #9 was prepared by mixing the following ingredients:

| | <u>Liquid</u> | <u>Proportion</u> | <u>Ratio</u> | <u>PPM at 2,000:1</u> |
|----|------------------|-------------------|--------------|-----------------------|
| | Span 80 | 50.0% | | |
| 10 | Ninate 411 | 30.0% | 8.0 | 400 |
| | Methanol | 5.0% | | |
| | Propylene Glycol | 5.0% | 1.0 | 50 |
| | Water | <u>10.0%</u> | 1.0 | <u>50</u> |
| | | 100.0% | | 500 |

15 Test #9a

Concentrated micro-emulsion additive #9 was mixed with California Reformulated #2 automotive diesel fuel using a treat rate of 500 ppm (2,000:1), or about 50 ppm of additional water.

- 20 This fuel was then used in a 1992 Dodge D250 pick up truck fitted with a Cummins 6 cylinder diesel engine (5.9 liter, direct injection, turbocharged and intercooled). Odometer reading was about 153,000 miles.

The exhaust smoke level was measured by the "snap-idle" test using a N.T.K. model ST-100 diesel emission smoke tester (manufactured by Komyo Rikagaku Kogyo K.K. of Japan).

- 25 Smoke levels reduced about 23% (average of 6 tests) using the emulsified fuel over the untreated fuel (opacity from 14.8% down to 11.3%).

Test #9b

Mileage testing on this same vehicle showed about a 1.5% improvement using the emulsified fuel over the untreated fuel (from 21.3 mpg up to 21.6 mpg).

1 Test #9c

The exhaust NO_x level was measured at idle using a "Nonoxor" NO_x analyzer (manufactured by Bacharach Inc., their model #19-7036).

NO_x levels reduced about 6% (average of 6 tests) using the emulsified fuel over the
5 untreated fuel (NO_x levels from 165 ppm down to 154 ppm).

Example #10

Additive #10

Concentrated micro-emulsion additive #10 was prepared by mixing the following ingredients:

| | | | | |
|----|-----------------|-------------------|--------------|-----------------------|
| 10 | <u>Liquid</u> | <u>Proportion</u> | <u>Ratio</u> | <u>PPM at 2,000:1</u> |
| | Kerosene | 20.0% | | 100 |
| | Surfonic N-40 | 30.0% | | |
| | Surfonic N-95 | 30.0% | 6.0 | 300 |
| | Ethylene Glycol | 10.0% | 1.0 | 50 |
| 15 | Water | <u>10.0%</u> | 1.0 | <u>50</u> |
| | | 100.0% | | 500 |

Test #10a

Concentrated micro-emulsion additive #10 was mixed with 92 octane unleaded gasoline using a treat rate of 500 ppm (2,000:1), or about 50 ppm of additional water. This fuel was then
20 used in a 1990 Lexus 400 (odometer reading about 250,000 miles) for 2 weeks using a typical daily commuter driving pattern.

Concentrated micro-emulsion additive #10 was then mixed with 87 octane unleaded gasoline using a treat rate of 500 ppm (2,000:1), or about 50 ppm of additional water.

The same Lexus 400 vehicle (which normally requires the use of untreated 92 octane
25 fuel) could then use this emulsified 87 octane fuel without any noticeable engine power loss, knocking or pinging, or driveability problems. Testing protocol was generally the CRC E-15-92 vehicle octane number requirement rating.

1 Test #10b

Mileage testing on this same vehicle showed about a 10% improvement using the 87 octane emulsified fuel over the 92 octane untreated fuel (from 19.0 mpg up to 20.0 mpg).

Test #10c

- 5 Exhaust emissions were also compared for this vehicle using the California Smog Check protocol (average of 6 tests). Comparison was between untreated 92 octane fuel, and emulsified 87 octane fuel (after the 2 week period described above). Average hydrocarbon (HC) emissions reduced from 20 ppm down to 12 ppm (a 40% reduction). Carbon monoxide (CO) emissions remained unchanged at 0.00% for both fuels (i.e. below the detection level of the test equipment).

10 Example #11

Additive #11

Concentrated micro-emulsion additive #11 was prepared by mixing the following ingredients:

| | <u>Liquid</u> | <u>Proportion</u> | <u>Ratio</u> | <u>PPM at 2,000:1</u> |
|----|-------------------|-------------------|--------------|-----------------------|
| 15 | Kerosene | 20.0% | | 100 |
| | CocoAmidoSultaine | 10.0% | | |
| | Ninate 411 | 60.0% | 7.0 | 350 |
| | Water | <u>10.0%</u> | 1.0 | <u>50</u> |
| | | 100.0% | | 500 |

- 20 Note: We actually used 20.0% Chembetaine CAS in our additive #11. Chembetaine CAS is 50% Cocoamidopropyl Hydroxyl Sultaine and 50% water. So 20.0% represents 10% Cocoamidopropyl Hydroxyl Sultaine and 10.0% water, i.e. we did not need to add any extra water.

Test 11a

- 25 Concentrated micro-emulsion additive #11 was mixed with California Reformulated #2 automotive diesel fuel using a treat rate of 500 ppm (2,000:1), or about 50 ppm of additional water.

1 This fuel was then used in a 1982 Mercedes Benz 300SD automobile fitted with a 5
cylinder diesel engine (3.0 liter, indirect injection, turbocharged). The odometer reading was
about 240,000 miles.

 The exhaust smoke level was measured by the “snap idle” test using a N.T.K. model
5 ST-100 diesel emission smoke tester (manufactured by Komyo Rigagku Kogyo K.K. of Japan).

 After 2 weeks of typical commuter driving, the exhaust smoke levels were reduced about
18% (average of 6 tests) from using the emulsified fuel over the untreated fuel (opacity reduction
from 18.8% down to 15.5%)

Test 11b

10 Mileage testing on this same vehicle showed about a 6% improvement using the
emulsified fuel over the untreated fuel (from 24.1 mpg up to 25.5 average).

Test 11c

 The exhaust NO_x level was measured at idle using a “Nonoxor” NO_x analyzer
(manufactured by Bacharach Inc., their model #19-7036). NO_x levels reduced about 5% (average
15 of 6 tests) using the emulsified fuel over the untreated fuel (NO_x levels down from 75 ppm down
to 71 ppm).

Example #12

Additive #12

 Concentrated micro-emulsion additive #12 was prepared by mixing the following
20 ingredients:

| | <u>Liquid</u> | <u>Proportion</u> | <u>Ratio</u> | <u>PPM at 2,000:1</u> |
|----|-------------------|-------------------|--------------|-----------------------|
| | Arquat T-50 | 20.0% | | |
| | Span 80 | 50.0% | 7.0 | 350 |
| | Isopropyl Alcohol | 20.0% | 2.0 | 100 |
| 25 | Water | <u>10.0%</u> | 1.0 | <u>50</u> |
| | | 100.0% | | 500 |

Note: We actually used 40.0% Arquat T-50 in our additive #12. Arquat T-50 is 50% Trimethyl
Tallowalkyl Quaternary Ammonium Chloride and 50% isopropyl alcohol (IPA). So this

1 40.0% represents 20% Trimethyl Tallowalkyl Quat and 20.0% isopropyl alcohol. i.e. we
did not need to add any extra IPA to act as the co-surfactant.

Test #12a

Concentrated micro-emulsion additive #12 was mixed with 87 octane unleaded California
5 reformulated gasoline using a treat rate of 500 ppm (2,000:1), or about 50 ppm of additional
water.

This fuel was then used in a 1992 Honda Accord 4 door sedan fitted with the 2.1 liter, 4
cylinder, 16 valve, fuel injected gasoline engine. The odometer reading was about 108,000
miles.

10 After 2 weeks of typical commuter driving, the exhaust emissions were then compared
for this vehicle using the California Smog Check protocol (average of 6 tests). Comparison was
between untreated 87 octane fuel, and emulsified 87 octane fuel.

Average hydrocarbon (HC) emissions reduced from 16 ppm down to 8 ppm (about a 50%
reduction). Carbon monoxide (CO) emissions remained unchanged at 0.00% for both fuels (i.e.
15 below the detection level of the test equipment).

Test #12b

Mileage testing on this same vehicle showed about a 10% improvement using the 87
octane emulsified fuel over the 87 octane untreated fuel (from 32.9 mpg up to 36.2 mpg average).

Comments on Test Results (Examples #1 through #12)

20 Examples #1 through #12 show that it is possible to employ significantly different types of
surfactants and co-surfactants and still achieve a reasonable result, even with a very low
water content (typically only 50 ppm additional water in the fuel).

Example #1 uses only one surfactant.

25 Examples #2 through #12 use mixtures of surfactants.

Examples #1 and #2 use ionic surfactants only.

Examples #3, 4, and 10 use non-ionic surfactants only.

1 Examples #5 through #9 use mixtures of ionic and non-ionic surfactants.

Example #11 uses a mixture of amphoteric and anionic surfactants.

Example #12 uses a mixture of cationic and non-ionic surfactants.

Examples #8 and #11 use no co-surfactants.

5 Examples #1, 2, 3, 4, 6, 7, 10 and #12 use only one co-surfactant.

Examples #5 and #9 use a mixture of co-surfactants.

Examples #1,2,3,4,5,6,7 and #12 use different alcohols as co-surfactants.

Examples #9 and #10 use different glycols as co-surfactants.

10 Example #9 uses a mixture of alcohol and glycol co-surfactants.

Examples #2, 4 ,9 and #11 use diesel as the hydrocarbon fuel.

Examples #1, 3, 5, 6, 7, 8,10 and #12 use gasoline as the hydrocarbon fuel.

It is obvious from the test results that some additives are much better than others in the
15 critical ratio of performance to cost per gallon treated. It is this ratio that determines to a large
extent the commercial acceptability of any given additive. For this reason, we have not included
any examples having a “large” water content (over 200 ppm). These additives would have
required proportionally greater quantities of surfactants, and would therefore have been
prohibitively expensive to use. If we double the water content, we would also have to almost
20 double the surfactant content, and hence almost double the price. The question would then be,
do we get double the performance for double the price? Comparison between examples #6 and
#8 clearly show that this would not be the case.

25 Comparing examples #1 through #12, clearly #2 would be the “best” diesel fuel additive
and #6 would be the “best” gasoline additive based simply on the cost/benefit ratio.

However, there appears to be no great difference between most of the surfactant mixtures
used in examples #1 through #12. When deciding whether one additive would be better than

1 another, other factors may have to be considered. For example, additive #2 would be illegal in
the USA because one of the surfactants used contains the metal sodium.

With regard to the best co-surfactant to use, we have found that butyl alcohol usually
gives the strongest emulsions because of its solubility compromise between water and
5 hydrocarbon. However, other factors such as flash point and freeze suppression must also be
considered. For fuels subject to extremely low ambient temperatures, we generally prefer
ethylene glycol as the co-surfactant (freezing points below - 40 deg C can be produced).

In order to maximize the cost/benefit ratio of our additives, we have tried where possible
to select surfactants which not only make a more stable emulsion but also perform additional
10 functions such as lubrication, corrosion resistance and biocide action (important in an emulsion).

Generally, a minimum number of at least two surfactants would be required (each one
acting against the other in order to achieve exactly the right HLB balance for the specific fuel
being emulsified), in this way the minimum quantity of surfactant necessary to achieve long term
fuel stability could be realized. For a good technical explanation of this phenomena please refer
15 to McCoy (US# 3,876,391).

Gasoline emulsions usually require a slightly different HLB balance than diesel
emulsions. However, it is possible to formulate an additive with an excess of surfactants such
that adequate results could be obtained irrespective of the hydrocarbon fuel being treated (i.e. the
same additive could be used in both gasoline and diesel fuel). Even fuels within a specific group
20 will still vary slightly with regard to their required HLB balance. Some diesel fuels requiring
more or slightly different surfactants than others. For this reason we prefer to have a larger
quantity of surfactant than is strictly necessary to be sure of obtaining long term fuel stability.

In examples #1 through #12 we have used only one or two surfactants to produce the
additives and consequently formed relatively "crude" additives. Those skilled in the art of
25 surfactant chemistry would easily be able to improve on the effectiveness of the surfactant(s) and
co-surfactant(s) chemical package and hence produce more "sophisticated" additives. This would

- 1 allow for the use of less surfactants per unit of water emulsified, and hence significantly improve cost effectiveness.

Examples #1 through #12 require a “crude” surfactant to water ratios typically 6:1 in order to produce sufficiently stable fuel emulsions. However, when using “sophisticated”

- 5 surfactant packages, typical ratios would be 3:1 or less (sometimes much less).

Examples #13 through #20 which follow are used to demonstrate how the use of more “sophisticated” chemical packages can significantly reduce the quantities of surfactants required, and thereby improve the cost effectiveness of the additive.

TABLE 4 (Percentage Composition For Examples #13 through #20):

| | #13 | #14 | #15 | #16 | #17 | #18 | #19 | #20 |
|------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 10 Kerosene | - | - | - | 16.7 | - | - | - | - |
| Amine alkylbenzene sulphonate | 21.3 | 21.3 | 21.3 | 26.7 | 21.2 | 21.4 | 27.4 | 22.2 |
| POE (20) sorbitan monoleate | 10.4 | 10.4 | 10.4 | 3.3 | 7.7 | 12.9 | 16.5 | 2.2 |
| Tall oil fatty acids | 9.2 | 9.2 | 9.2 | 6.6 | 15.3 | 5.3 | 6.8 | - |
| 15 Oleyl imidazoline hydrochloride | 4.8 | 4.8 | 4.8 | - | - | 6.4 | 8.2 | - |
| Oleamide diethanolamine | 8.0 | 8.0 | 8.0 | 13.3 | 7.7 | 10.7 | 13.6 | 4.5 |
| Methanol | 18.0 | 18.0 | 18.0 | - | - | 16.1 | 20.6 | - |
| Iso propanol | - | - | - | 16.7 | 14.3 | - | - | - |
| N-butanol | - | - | - | - | - | - | - | 11.6 |
| 20 Ethylene glycol n-butyl ether | 3.2 | 3.2 | 3.2 | - | - | 4.3 | 5.5 | - |
| Dipropylene glycol methyl ether | 0.7 | 0.7 | 0.7 | - | - | 1.1 | 1.4 | 2.3 |
| Water | <u>24.4</u> | <u>24.4</u> | <u>24.4</u> | <u>16.7</u> | <u>33.8</u> | <u>21.8</u> | <u>00.0</u> | <u>57.2</u> |
| Total(%) | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

TABLE 5 (Dose Ratio ppm For Various Examples):

| | #13 | #14 | #15 | #16 | #17 | #18 | #19 | #20 |
|---------------------|------|-----|-----|-----|-----|-----|-----|-----|
| 25 Hydrocarbon fuel | Gas | Gas | Gas | Gas | Gas | #2D | #2D | Gas |
| Dose Ratio | 7.5K | 12K | 50K | 4K | 4K | 10K | 10K | 6K |
| Kerosene | 0 | 0 | 0 | 42 | 0 | 0 | 0 | 0 |

| | | | | | | | | | |
|---|--------------------|-----------|-----------|----------|-----------|-----------|-----------|----------|-----------|
| 1 | Surfactant(s) | 72 | 45 | 11 | 124 | 130 | 57 | 72 | 48 |
| | Co-surfactant(s) | 29 | 18 | 4 | 42 | 35 | 21 | 28 | 23 |
| | Water | <u>32</u> | <u>20</u> | <u>5</u> | <u>42</u> | <u>85</u> | <u>22</u> | <u>0</u> | <u>95</u> |
| | Total ppm in fuel | 133 | 83 | 20 | 250 | 250 | 100 | 100 | 166 |
| 5 | Treatment cost/gal | 11 | 7 | 2 | 23 | 18 | 9 | 11 | 7 |

Note:

a. Dose ratio 4K = 4,000:1, and 7.5K = 7,500:1. Dose ratio used was based on the relative emulsifying ability of each particular additive surfactant/co-surfactant combination. Some additives were much stronger than others, and could be used at a lower dose rate.

10 b. Treatment costs/gallon are all relative and for comparison only, based on example #12 (the most expensive of all our examples) being given the arbitrary value of 100.

TABLE 6 (Performance Analysis Tests #1 through #20)

| | Test # | Cost | Water | Emissions Reduction | | | | |
|----|--------|------|-------|---------------------|----|----|-----|----|
| | | | | MPG | HC | CO | NOX | PM |
| 15 | 1 | 55 | 50 | 10 | 20 | -- | -- | -- |
| | 2 | 17 | 50 | 6 | -- | -- | 5 | 15 |
| | 3 | 51 | 50 | 10 | 60 | -- | -- | -- |
| | 4 | 95 | 50 | -- | -- | -- | 3 | 6 |
| | 5 | 99 | 50 | 4 | 6 | -- | -- | -- |
| 20 | 6 | 25 | 50 | 10 | 50 | -- | -- | -- |
| | 7 | 89 | 50 | 2 | 90 | -- | -- | -- |
| | 8 | 52 | 50 | 5 | 45 | -- | -- | -- |
| | 9 | 88 | 50 | 2 | -- | -- | 6 | 23 |
| | 10 | 42 | 50 | 10 | 40 | -- | -- | -- |
| 25 | 11 | 56 | 50 | 6 | -- | -- | 5 | 18 |
| | 12 | 100 | 50 | 10 | 50 | -- | -- | -- |
| | 13 | 11 | 32 | -- | 13 | 10 | 36 | -- |

| | | | | | | | | |
|---|----|----|----|----|----|-----|----|----|
| 1 | 14 | 7 | 20 | 10 | 80 | -- | -- | -- |
| | 15 | 2 | 5 | 22 | 50 | -- | -- | -- |
| | 16 | 23 | 42 | 12 | 52 | 85 | 1 | -- |
| | 17 | 18 | 85 | -- | 98 | +35 | 95 | -- |
| 5 | 18 | 9 | 22 | 14 | 49 | -- | 9 | 22 |
| | 19 | 11 | 0 | -- | -- | -- | 5 | 15 |
| | 20 | 7 | 95 | 10 | 90 | -- | -- | -- |

Example #13

Additive #13

- 10 Concentrated micro-emulsion additive #13 was prepared by mixing the following ingredients:

| | <u>Liquid</u> | <u>Proportion (%)</u> | <u>Ratio</u> | <u>PPM at 7,500:1</u> |
|----|---------------------------------|-----------------------|--------------|-----------------------|
| | Amine alkylbenzene sulphonate | 21.3 | | |
| | POE (20) sorbitan monooleate | 10.4 | 2.25 | 72 |
| 15 | Tall oil fatty acids | 9.2 | | |
| | Oleyl imidazoline hydrochloride | 4.8 | | |
| | Oleamide diethanolamine | 8.0 | | |
| | Methanol | 18.0 | 0.9 | 29 |
| | Ethylene glycol n-butyl ether | 3.2 | | |
| 20 | Dipropylene glycol methyl ether | 0.7 | | |
| | Water | <u>24.4</u> | 1.0 | <u>32</u> |
| | | 100.0% | | 133 |

Test #13

- Concentrated micro-emulsion additive #13 was mixed with 87 octane unleaded gasoline
- 25 using a treat rate of 133 ppm (7,500:1), or about 32 ppm of additional water. This fuel was then used in a 1993 Dodge Shadow automobile. This vehicle was then tested using Federal Test Procedure (FTP) described in 40 CFR § 600, appendix 1.

1 The following results indicate exhaust emissions reductions for both city and highway driving:-

| | <u>Emission Gas</u> | <u>City Driving</u> | <u>Highway Driving</u> |
|---|-----------------------|---------------------|------------------------|
| | HC (hydrocarbons) | -7.3% | -18.8% |
| 5 | CO (carbon monoxide) | -5.0% | -14.7% |
| | NOx (nitrogen oxides) | -11.8% | -29.9% |

Example #14

Additive #14

Concentrated micro-emulsion additive #14 was prepared by mixing the following
10 ingredients:

| | <u>Liquid</u> | <u>Proportion (%)</u> | <u>Ratio</u> | <u>PPM at 12,000:1</u> |
|----|---------------------------------|-----------------------|--------------|------------------------|
| | Amine alkylbenzene sulphonate | 21.3 | | |
| | POE (20) sorbitan monooleate | 10.4 | 2.25 | 45 |
| | Tall oil fatty acids | 9.2 | | |
| 15 | Oleyl imidazoline hydrochloride | 4.8 | | |
| | Oleamide diethanolamine | 8.0 | | |
| | Methanol | 18.0 | 0.9 | 18 |
| | Ethylene glycol n-butyl ether | 3.2 | | |
| | Dipropylene glycol methyl ether | 0.7 | | |
| 20 | Water | <u>24.4</u> | 1.0 | <u>20</u> |
| | | 100.0% | | 83 |

Test #14a

Concentrated micro-emulsion additive #14 was mixed with 92 octane unleaded gasoline using a treat rate of 83 ppm (12,000:1), or about 20 ppm of additional water. This fuel was then
25 used in a 1990 Lexus 400 (odometer reading about 250,000 miles) for 2 weeks using a typical daily commuter driving pattern.

Concentrated micro-emulsion additive #14 was then mixed with 89 octane unleaded gasoline using a treat rate of 83 ppm (12,000:1), or about 20 ppm of additional water.

1 The same Lexus 400 vehicle (which normally requires the use of untreated 92 octane fuel) could then use this emulsified 89 octane fuel without any noticeable engine power loss, knocking, pinging, or driveability problems. Testing protocol was generally the CRC E-15-92 vehicle octane number requirement rating.

5 Test #14b

Mileage testing on this same vehicle showed about a 10% improvement using the 89 octane emulsified fuel over the 92 octane untreated fuel (from 19.0 mpg up to 20.9 mpg).

Test #14c

Exhaust emissions were also compared for this vehicle using the California Smog
10 protocol (average of 6 tests). Comparison was between untreated 92 octane fuel, and emulsified 89 octane fuel (after the 2 week period described above). Average hydrocarbon (HC) emissions reduced 20 ppm down to 4 ppm (a 80% reduction). Carbon monoxide (CO) emissions remained unchanged at 0.00% for both fuels (i.e. below the detection level of the test equipment).

Example #15

15 Additive #15

Concentrated micro-emulsion additive #15 was prepared by mixing the following ingredients:

| | <u>Liquid</u> | <u>Proportion (%)</u> | <u>Ratio</u> | <u>PPM at 50,000:1</u> |
|----|---------------------------------|-----------------------|--------------|------------------------|
| | Amine alkylbenzene sulphonate | 21.3 | | |
| 20 | POE (20) sorbitan monooleate | 10.4 | 2.25 | 11 |
| | Tall oil fatty acids | 9.2 | | |
| | Oleyl imidazoline hydrochloride | 4.8 | | |
| | Oleamide diethanolamine | 8.0 | | |
| | Methanol | 18.0 | 0.9 | 4 |
| 25 | Ethylene glycol n-butyl ether | 3.2 | | |
| | Dipropylene glycol methyl ether | 0.7 | | |
| | Water | <u>24.4</u> | 1.0 | <u>5</u> |
| | | 100.0% | | 20 |

1 Test #15a

Having just completed test #14, the fuel remaining in the fuel tank of the Lexus 400 test vehicle was estimated to be about 4 gallons (test fuel #14 having 20 ppm of additional water). Exactly 12 gallons of untreated 89 octane gasoline was then added to this fuel tank. In this way, test fuel #14 was diluted to make test fuel #15 (which should then contain about 5 ppm of additional water). Equivalent dose ratio of 50,000:1 was estimated for this fuel (as shown above).

The same Lexus 400 vehicle (which normally requires the use of untreated 92 octane fuel) could then use this diluted emulsified 89 octane fuel without any noticeable engine power loss, knocking, pinging, or driveability problems. Testing protocol was generally the CRC E-15-92 vehicle octane number requirement rating.

Test #15b

Mileage testing on this same vehicle still showed about a 2.5% improvement using the 89 octane emulsified fuel over the 92 octane untreated fuel (from 19.0 mpg up to 19.5 mpg).

15 Test #15c

Exhaust emissions were also compared for this vehicle using the California Smog protocol (average of 6 tests). Comparison was between untreated 92 octane fuel, and diluted emulsified 89 octane fuel. Average hydrocarbon (HC) emissions reduced 20 ppm down to 10 ppm (a 50% reduction). Carbon monoxide (CO) emissions remained unchanged at 0.00% for both fuels (i.e. below the detection level of the test equipment).

Example #16

Additive #16

Concentrated micro-emulsion additive #16 was prepared by mixing the following ingredients:

| | | | | |
|----|-------------------------------|-----------------------|--------------|-----------------------|
| 25 | <u>Liquid</u> | <u>Proportion (%)</u> | <u>Ratio</u> | <u>PPM at 4,000:1</u> |
| | Kerosene | 16.7 | ---- | 42 |
| | Amine alkylbenzene sulphonate | 26.7 | | |
| | POE (20) sorbitan monooleate | 3.3 | 2.95 | 124 |

| | | | | |
|---|-------------------------|-------------|-----|-----------|
| 1 | Tall oil fatty acids | 6.6 | | |
| | Oleamide diethanolamine | 13.3 | | |
| | Iso-propanol | 16.7 | 1.0 | 42 |
| | Water | <u>16.7</u> | 1.0 | <u>42</u> |
| 5 | | 100.0% | | 250 |

Test #16

Concentrated micro-emulsion additive #16 was mixed with 85 octane unleaded gasoline using a treat rate of 250 ppm (4,000:1), or about 42 ppm of additional water. This fuel was then used in a 1995 Toyota Corolla automobile. This vehicle was then tested for exhaust emission reductions using the EPA "IM240" test protocol at one of the State of Colorado official smog check stations.

The following results indicate exhaust emissions reductions:-

| | <u>Emission Gas</u> | <u>Reduction</u> |
|----|-----------------------|------------------|
| | HC (hydrocarbons) | - 52% |
| 15 | CO (carbon monoxide) | - 85% |
| | NOx (nitrogen oxides) | - 1% |
| | CO2 (carbon dioxide) | - 12% |

Example #17

Additive #17

Concentrated micro-emulsion additive #17 was prepared by mixing the following ingredients:

| | <u>Liquid</u> | <u>Proportion (%)</u> | <u>Ratio</u> | <u>PPM at 4,000:1</u> |
|----|-------------------------------|-----------------------|--------------|-----------------------|
| | Amine alkylbenzene sulphonate | 21.2 | | |
| | POE (20) sorbitan monooleate | 7.7 | 1.53 | 130 |
| 25 | Tall oil fatty acids | 15.3 | | |
| | Oleamide diethanolamine | 7.7 | | |
| | Iso-propanol | 14.3 | 0.4 | 35 |
| | Water | <u>33.8</u> | 1.0 | <u>85</u> |

Test #17

Concentrated micro-emulsion additive #17 was mixed with 85 octane unleaded gasoline using a treat rate of 250 ppm (4,000:1), or about 85 ppm of additional water. This fuel was then used in a 1995 Ford Taurus automobile. This vehicle was then tested for exhaust emission reductions using the EPA "IM240" test protocol at one of the State of Colorado official smog check stations.

The following results indicate exhaust emissions reductions:-

| | <u>Emission Gas</u> | <u>Reduction</u> |
|----|----------------------------------|------------------|
| 10 | HC (hydrocarbons) | - 98% |
| | CO (carbon monoxide) | + 35% |
| | NOx (nitrogen oxides) | - 95% |
| | CO ₂ (carbon dioxide) | no change |

Example #1815 Additive #18

Concentrated micro-emulsion additive #18 was prepared by mixing the following ingredients:

| | <u>Liquid</u> | <u>Proportion (%)</u> | <u>Ratio</u> | <u>PPM at 10,000:1</u> |
|----|---------------------------------|-----------------------|--------------|------------------------|
| | Amine alkylbenzene sulphonate | 21.4 | | |
| 20 | POE (20) sorbitan monooleate | 12.9 | 2.59 | 57 |
| | Tall oil fatty acids | 5.3 | | |
| | Oleyl imidazoline hydrochloride | 6.4 | | |
| | Oleamide diethanolamine | 10.7 | | |
| | Methanol | 16.1 | 0.95 | 21 |
| 25 | Ethylene glycol n-butyl ether | 4.3 | | |
| | Dipropylene glycol methyl ether | 1.1 | | |
| | Water | <u>21.8</u> | 1.0 | <u>22</u> |
| | | 100.0% | | 100 |

1 Test #18

Concentrated micro-emulsion additive #18 was mixed with the Chinese equivalent of US #2 diesel fuel using a treat rate of 100 ppm (10,000:1), or about 22 ppm of additional water. This fuel was then used in a 2½ ton Tong Fung truck. This vehicle was then tested by the official

5 Chinese EPA for exhaust emission reductions using their “GB3842-3847-83” test protocol.

The following results indicate exhaust emissions reductions:-

| | <u>Emission Gas</u> | <u>Reduction</u> |
|----|-----------------------|------------------|
| | HC (hydrocarbons) | + 49% |
| | CO (carbon monoxide) | no change |
| 10 | NOx (nitrogen oxides) | - 9% |
| | CO2 (carbon dioxide) | - 14% |
| | Exhaust smoke | - 22% |

Concerning the higher than baseline HC emissions shown above, these are almost certainly caused by combustion chamber cleaning action of the fuel emulsion. If the truck would have been allowed to accumulate some highway/city mileage then this would have given time for the combustion chambers to be cleaned, and lower than baseline HC emissions realized.

Example #19

Additive #19

Concentrated micro-emulsion additive #19 was prepared by mixing the following ingredients:

| | <u>Liquid</u> | <u>Proportion (%)</u> | <u>Ratio</u> | <u>PPM at 10,000:1</u> |
|----|---------------------------------|-----------------------|--------------|------------------------|
| | Amine alkylbenzene sulphonate | 27.4 | | |
| | POE (20) sorbitan monooleate | 16.5 | ---- | 72 |
| | Tall oil fatty acids | 6.8 | | |
| 25 | Oleyl imidazoline hydrochloride | 8.2 | | |
| | Oleamide diethanolamine | 13.6 | | |
| | Methanol | 20.6 | ---- | 28 |
| | Ethylene glycol n-butyl ether | 5.5 | | |

| | | | | |
|---|---------------------------------|------------|-----|------------|
| 1 | Dipropylene glycol methyl ether | 1.4 | | |
| | Water | <u>0.0</u> | 1.0 | <u>0.0</u> |
| | | 100.0% | | 100 |

Test #19a

- 5 Concentrated micro-emulsion additive #19 was mixed with California reformulated #2 automotive diesel fuel using a treat rate of 166 ppm (6,000:1). This fuel was then used in a 1982 Mercedes Benz 300SD automobile fitted with an in-line 5 cylinder, 3.0 liter, indirect injection, turbocharged diesel engine (odometer reading about 240,000 miles).

- This fuel, when first mixed, would not be a true emulsion (since there was no water phase
10 in additive #19). Initial driver response reported no power, and exhaust smoke/NO_x was within baseline tolerance. However, by about ½ tank power started to build and by ¼ tank feeling was good, so smoke and NO_x levels were measured.

- Exhaust smoke level was measured by the “snap idle” test using a N.T.K. model ST-100 diesel emission opacity/smoke tester (average of 6 readings). Exhaust smoke level had reduced
15 15% over baseline.

Test #19b

NO_x at idle was measured using a Nonoxor NO_x analyzer manufactured by Bacharach Inc., their model #19-7036. NO_x levels were reduced about 5% over baseline.

Test #19c

- 20 Fuel economy for the first tank of fuel was within baseline tolerance. However, economy for the second tank improved significantly, showing a 5% increase. Third tank mileage was a strong 8% better than baseline.

Example #20

Additive #20

- 25 Concentrated micro-emulsion additive #20 was prepared by mixing the following ingredients:

| <u>Liquid</u> | <u>Proportion (%)</u> | <u>Ratio</u> | <u>PPM at 6,000:1</u> |
|-------------------------------|-----------------------|--------------|-----------------------|
| Amine alkylbenzene sulphonate | 22.2 | | |

| | | | | |
|---|---------------------------------|-------------|------|-----------|
| 1 | POE (20) sorbitan monooleate | 2.2 | 0.50 | 48 |
| | Oleamide diethanolamine | 4.5 | | |
| | N-butanol | 11.6 | 0.24 | 23 |
| | Dipropylene glycol methyl ether | 2.3 | | |
| 5 | Water | <u>57.2</u> | 1.0 | <u>95</u> |
| | | 100.0% | | 166 |

Test #20a

Concentrated micro-emulsion additive #20 was mixed with 92 octane unleaded gasoline using a treat rate of 166 ppm (6,000:1), or about 95 ppm of additional water. This fuel was then
10 used in a 1990 Lexus 400 (odometer reading about 250,000 miles) for 2 weeks using a typical daily commuter driving pattern.

Concentrated micro-emulsion additive #20 was then mixed with 89 octane unleaded gasoline using a treat rate of 166 ppm (6,000:1), or about 95 ppm of additional water.

The same Lexus 400 vehicle (which normally requires the use of untreated 92 octane
15 fuel) could then use this emulsified 89 octane fuel without any noticeable engine power loss, knocking, pinging, or driveability problems. Testing protocol was generally the CRC E-15-92 vehicle octane number requirement rating.

Test #20b

Mileage testing on this same vehicle showed about a 10% improvement using the 89
20 octane emulsified fuel over the 92 octane untreated fuel (from 19.0 mpg up to 20.9 mpg).

Test #20c

Exhaust emissions were also compared for this vehicle using the California Smog protocol (average of 6 tests). Comparison was between untreated 92 octane fuel, and emulsified 89 octane fuel (after the 2 week period described above). Average hydrocarbon (HC) emissions
25 reduced 20 ppm down to 2 ppm (a 90% reduction). Carbon monoxide (CO) emissions remained unchanged at 0.00% for both fuels (i.e. below the detection level of the test equipment).